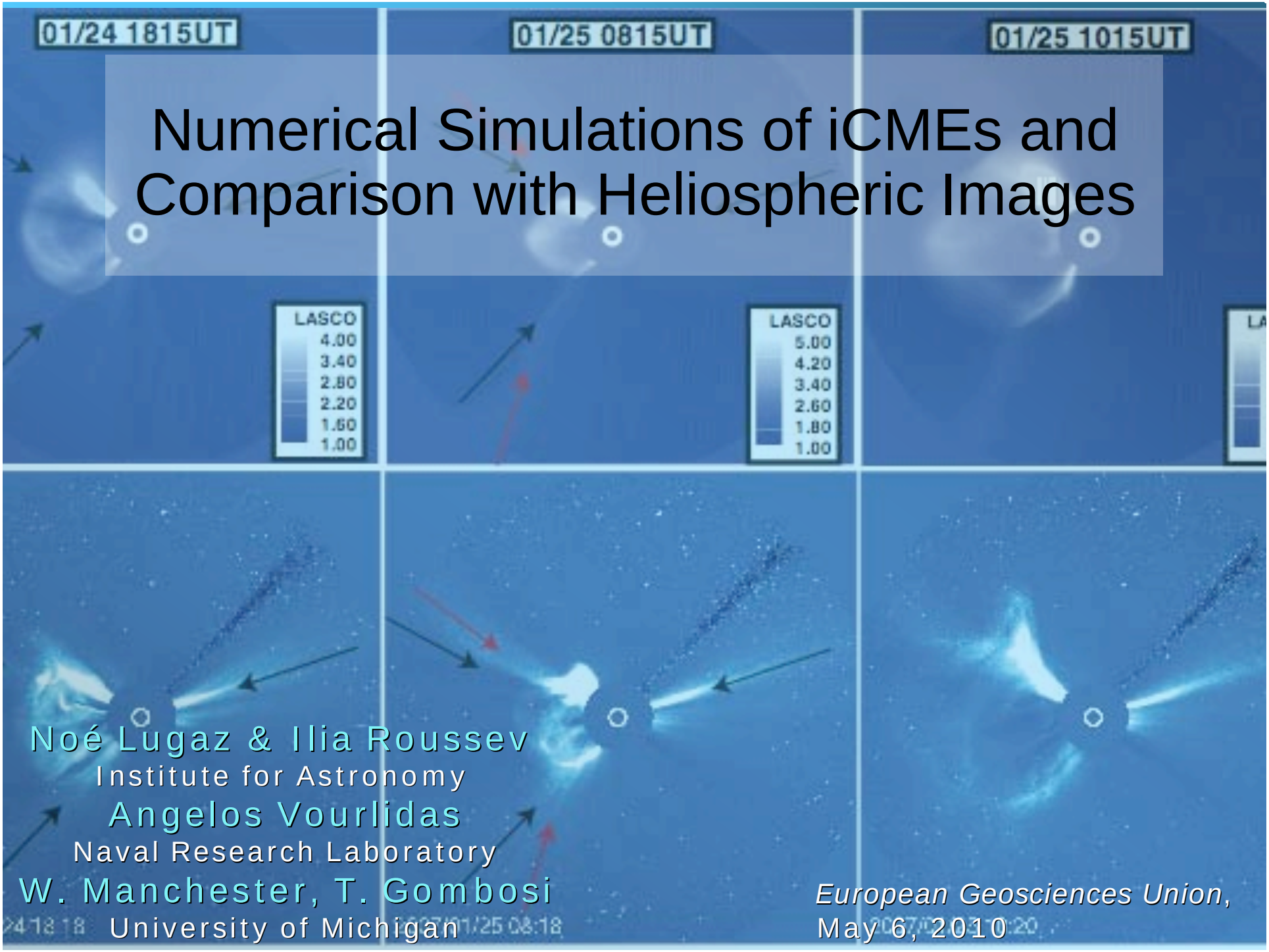

Numerical Simulations of iCMEs and Comparison with Heliospheric Images

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14. ABSTRACT

This paper presents the extension of some finite elements with embedded strong discontinuities to the fully transient range with the focus on dynamic fracture. Cracks and shear bands are modeled in this setting as discontinuities of the displacement field, the so-called strong discontinuities, propagating through the continuum. These discontinuities are embedded into the finite elements through the proper enhancement of the discrete strain field of the element. General elements, like displacement or assumed strain based elements, can be considered in this framework, capturing sharply the kinematics of the discontinuity for all these cases. The local character of the enhancement (local in the sense of defined at the element level, independently for each element) allows the static condensation of the different local parameters considered in the definition of the displacement jumps. All these features lead to an efficient formulation for the modeling of fracture in solids, very easily incorporated in an existing general finite element code due to its modularity. We investigate in this paper the use of this finite element formulation for the special challenges that the dynamic range leads to. Specifically, we consider the modeling of failure mode transitions in ductile materials and crack branching in brittle solids. To illustrate the performance of the proposed formulation, we present a series of numerical simulations of these cases with detailed comparisons with experimental and other numerical results reported in the literature. We conclude that these finite element methods handle well these dynamic problems, still maintaining the aforementioned features of computational efficiency and modularity.

15. SUBJECT TERMS

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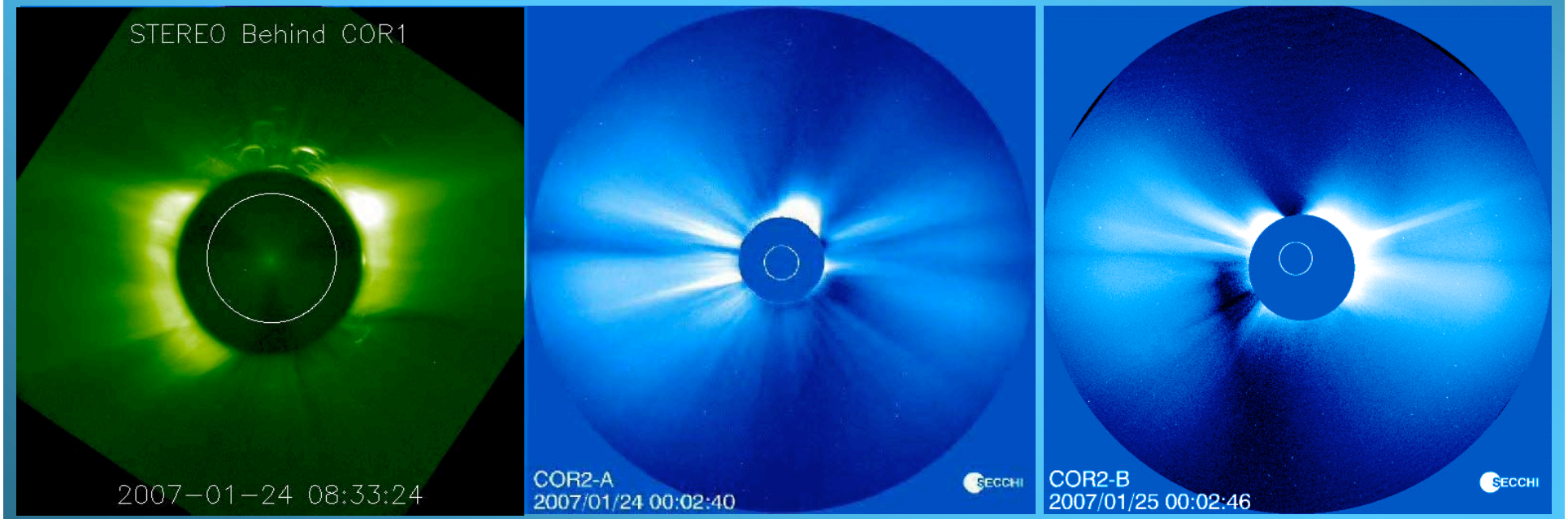
The 2007 January 24-26 CMEs

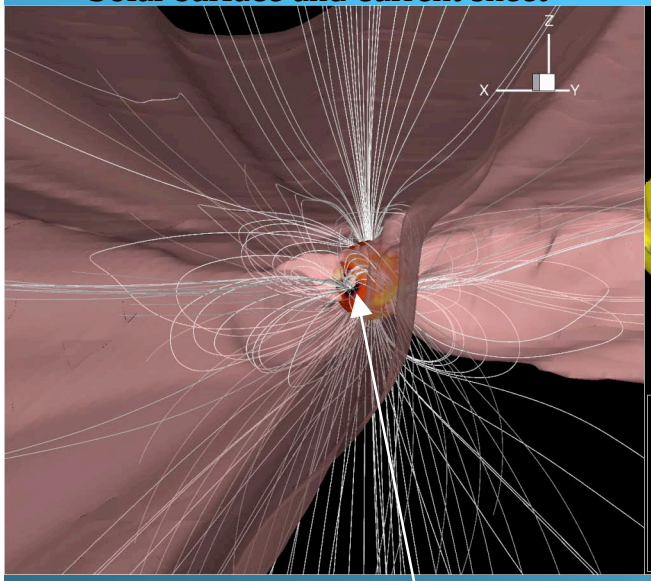
- First major CMEs observed by the SECCHI suite…
  … but with a 20 hour gap while the CMEs were in HI1's FOV.
- *1st CME*: 01/24 @14:03 ~700 km/s - *2nd CME*: 01/25 @06:43 ~1200 km/s
- Data gap: 01/25 06 UT to 01/26 00 UT
- Studied by Harrison et al. (2008) and Webb et al. (2009).
- Simulated by Lugaz et al. (2009) and Odstrcil et al. (2009).



Simulation set-up

- Space Weather Modeling Framework (Univ. Michigan)
- Solar wind model of Cohen et al. (2007), out-of-equilibrium flux ropes chosen to match initial observed speed.
- From $1R_{Sun}$ to 1 AU: 40,000 4^3 blocks + 15,000 8^3 blocks (> 10M cells)

Solar surface and current sheet



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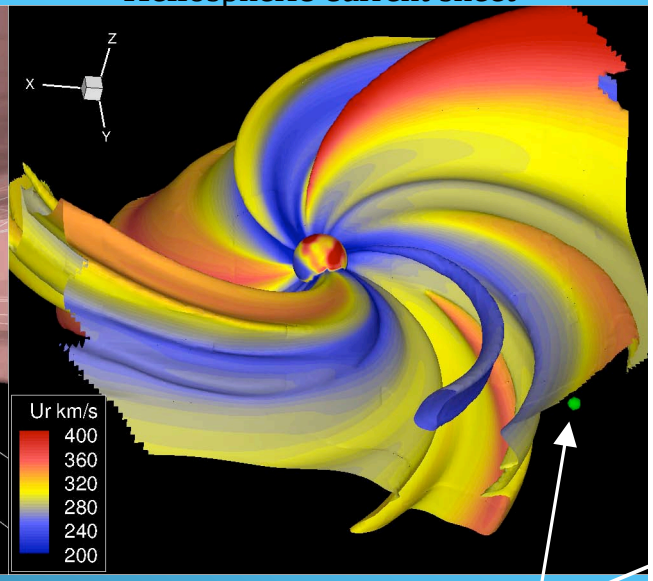
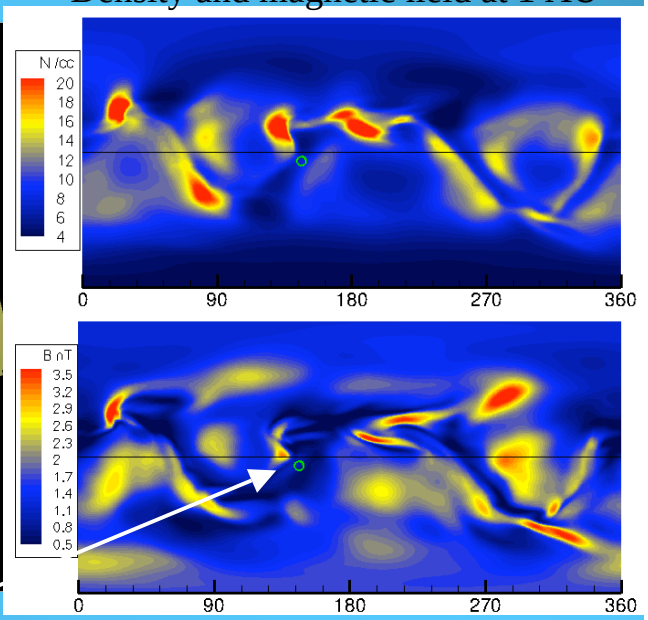
Heliospheric current sheet



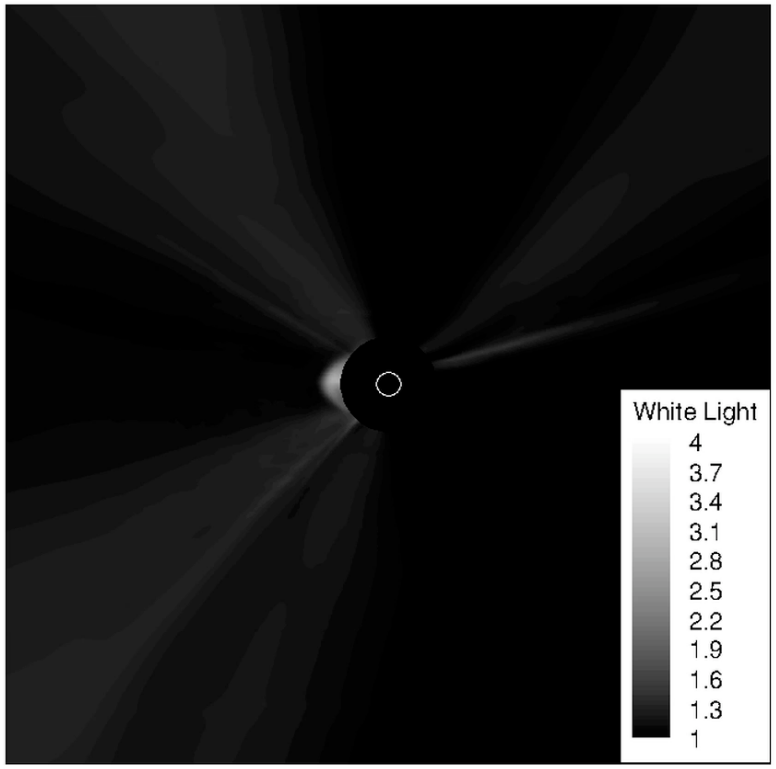
Earth (2007, January 24)

Density and magnetic field at 1 AU

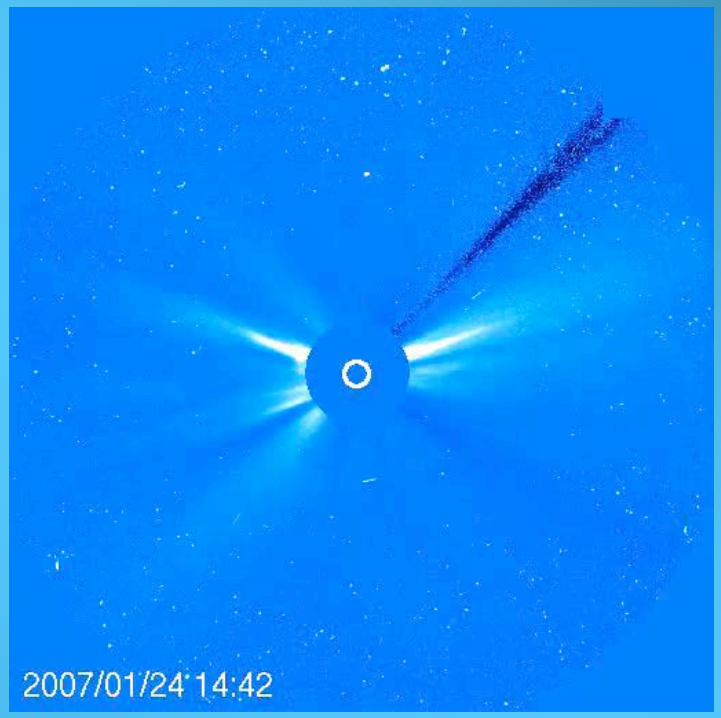


Line-of-sight images

- Simulated background is calculated by deriving the minimum image from 27 steady-state LOS images.

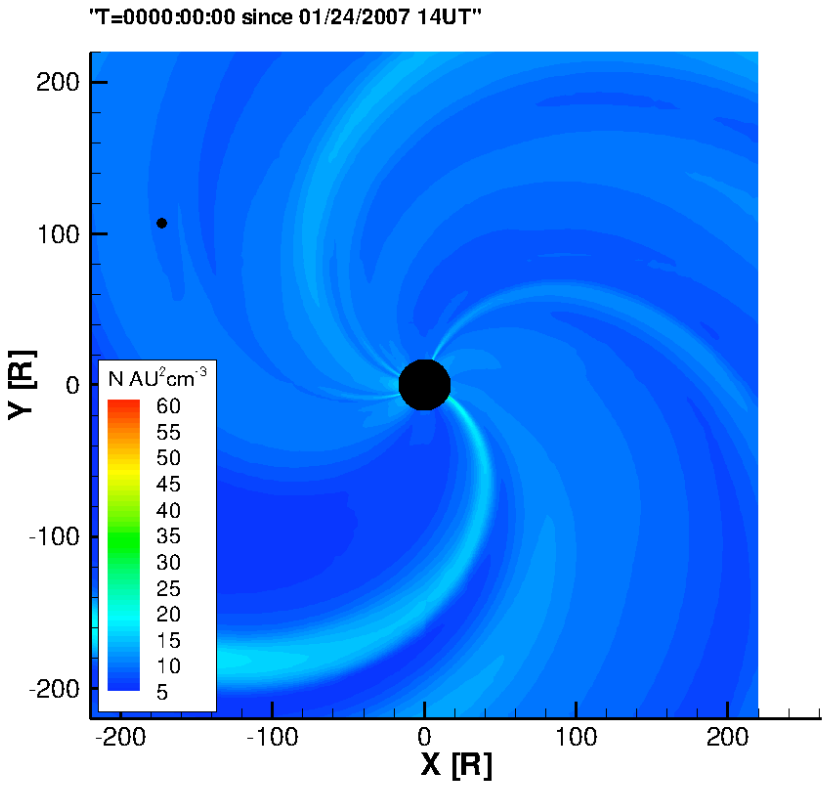


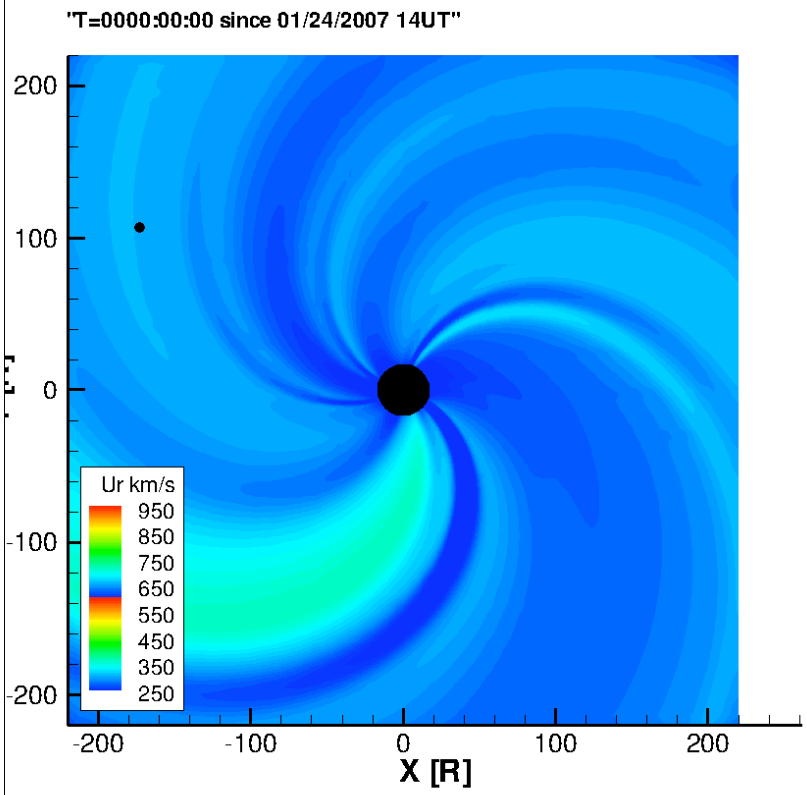
T = 15:00:00 since January 24, 2007 00 UT



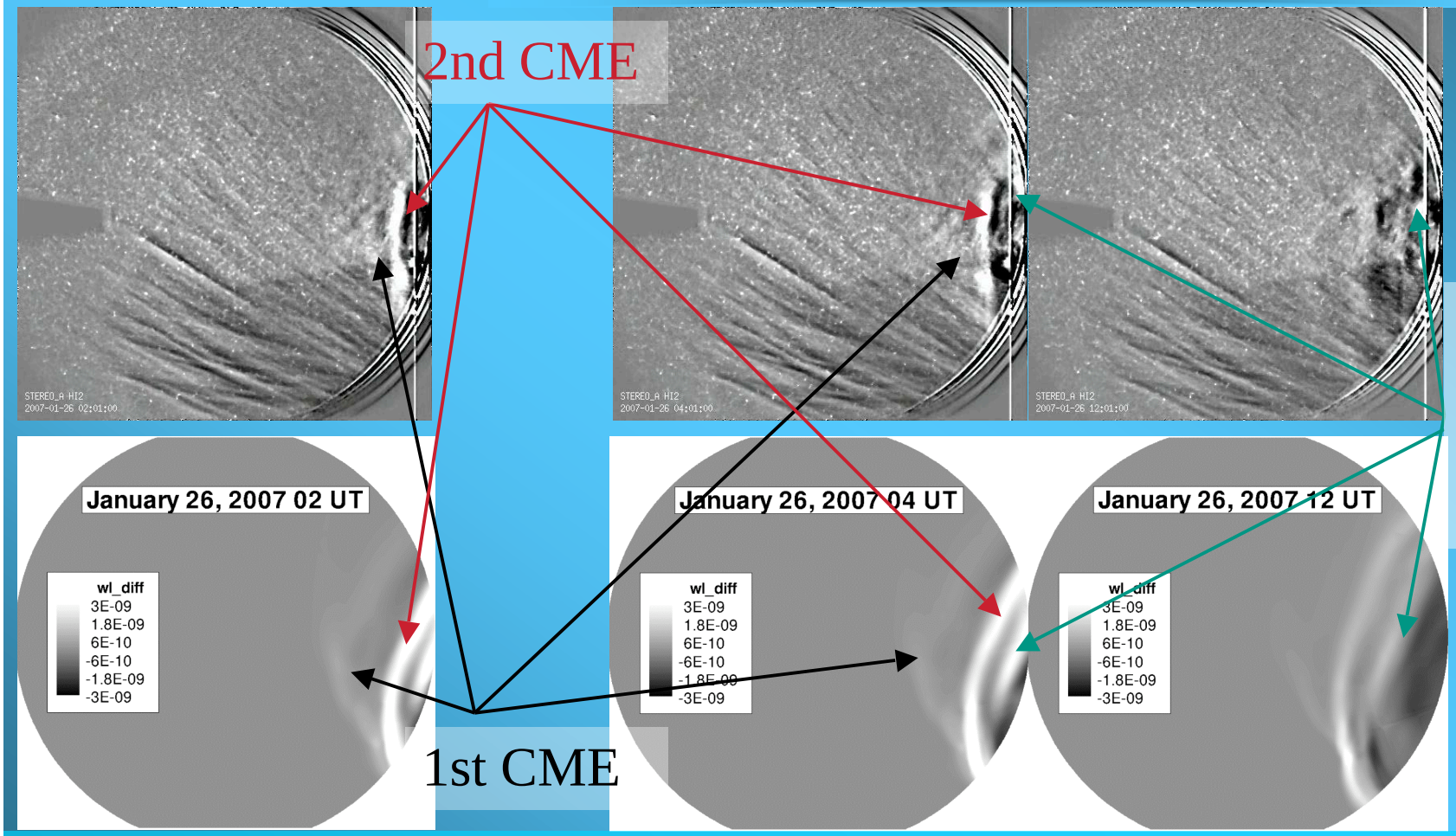
Heliospheric Evolution

- Near solar minimum: there are a number of steady structures (CIR-like).
- Interaction involves not only the 2 CMEs but also these dense streams.





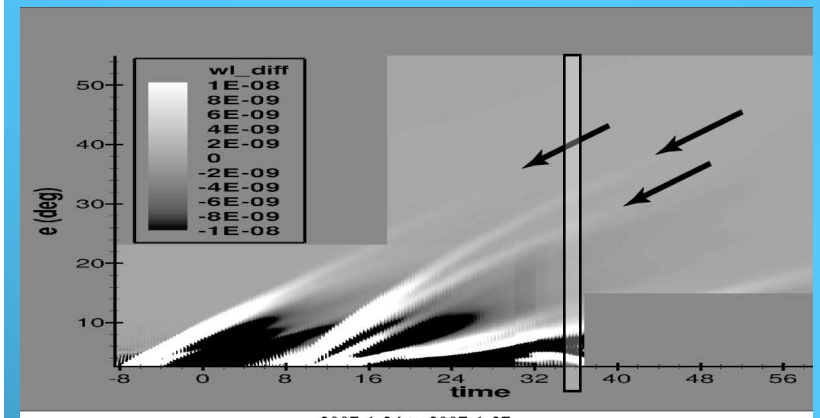
Heliospheric Imagers: what is being observed?

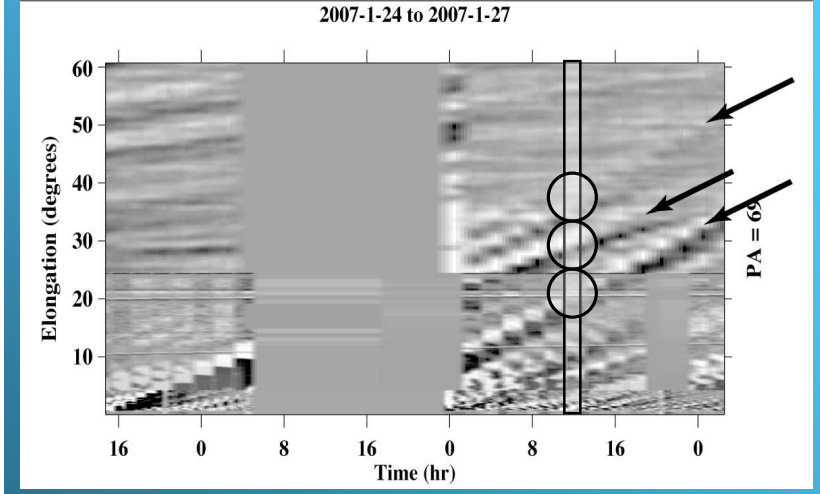


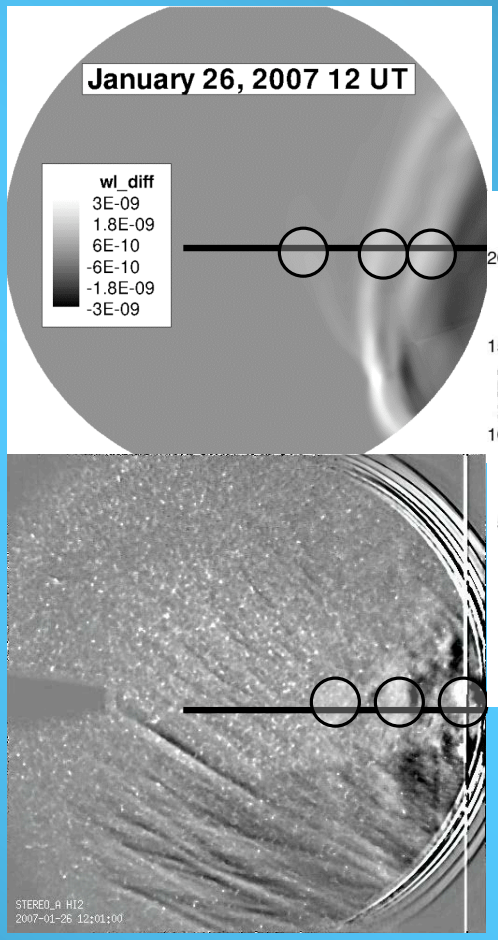
2nd CME is brighter because the leading front propagates inside the sheath of the 1st CME.

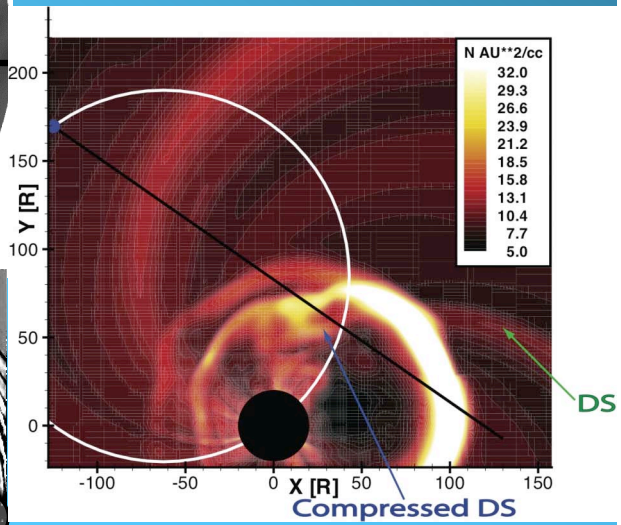
Dense stream can be identified as such in these images, because its propagation speed is different.

Time-elongation plots



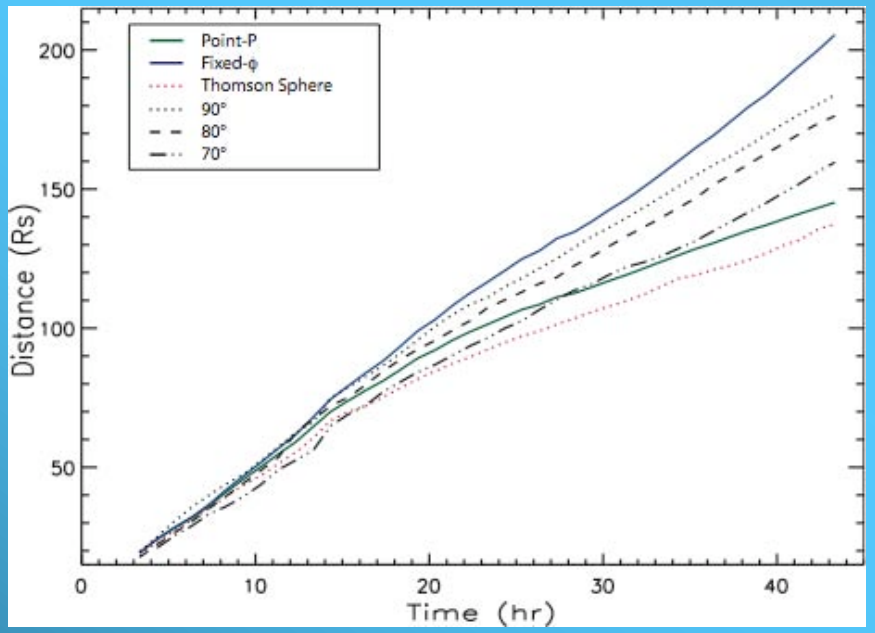


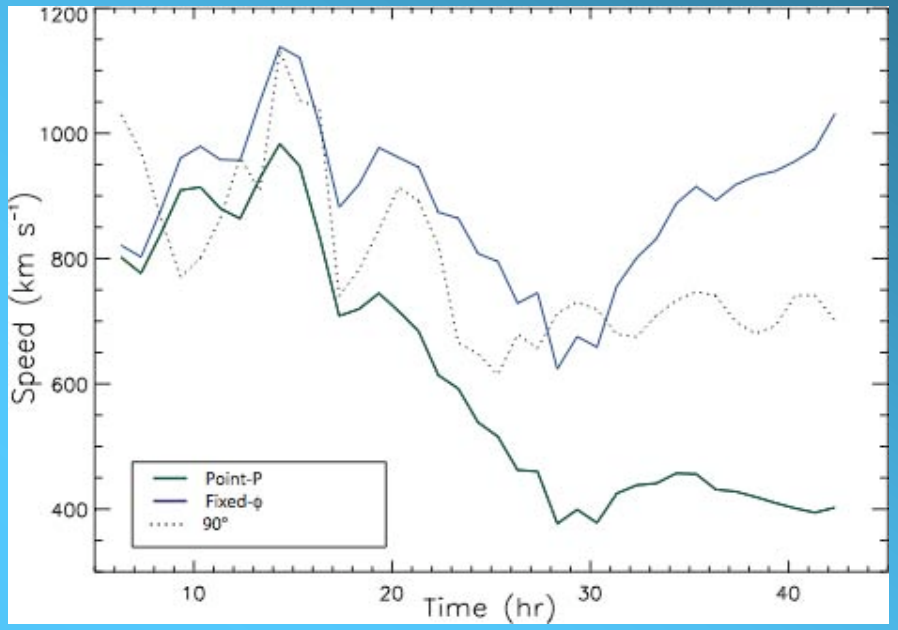




Time (from 01/25)-elongation plots for PA 69 (apparent central PA of SECCHI).

Simulations as laboratory: Testing position and velocity estimates

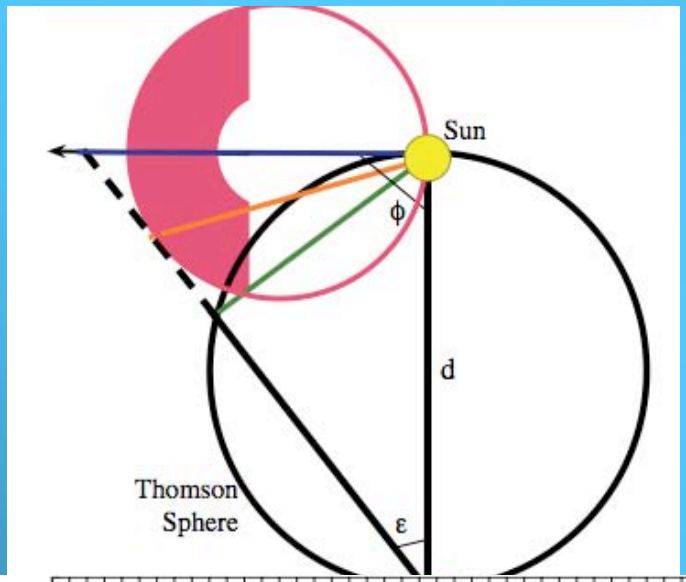




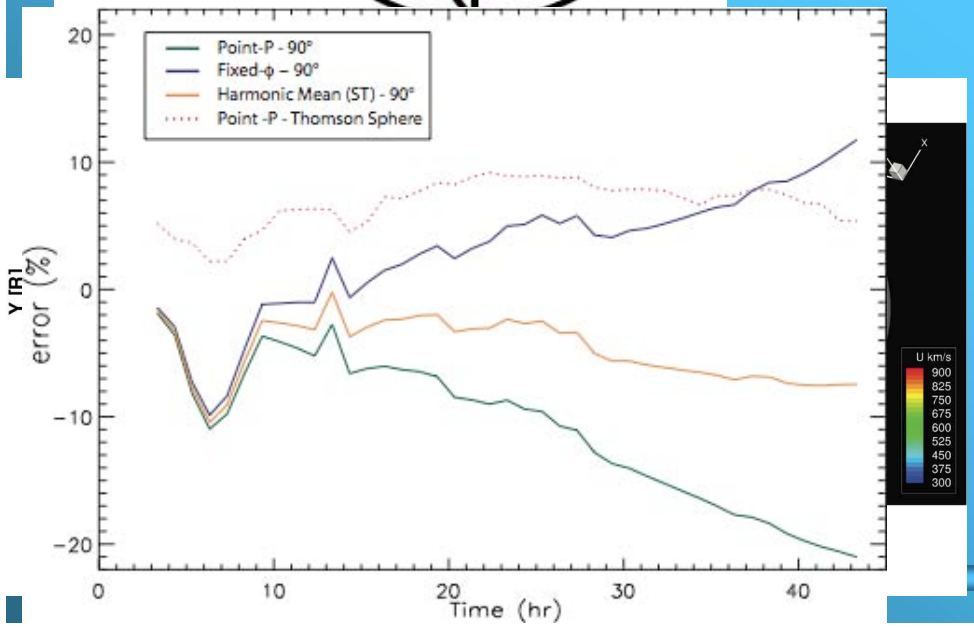
- Here testing method to derive position from elongation measurements (Kahler et al., Rouillard et al.).
  - Fixed-Phi: Approximates CME with a single point
  - Point-P: Approximates CME with an expanding sphere centered at the Sun
- Position is well determined up to 0.5 AU.
- Speed is not very well determined from existing methods, especially for wide, limb ejections past 0.5 AU.

New geometrical method to derive CME position from elongation angle

(Lugaz et al. Ann Geo, 2009)



- Instead of using single-point approximation or assuming a spherically symmetric front we use a sphere attached to the Sun.
- New assumption is good for wide CMEs (better than Point-P).
- It can be shown that:



$$r_{F\phi} = d \sin\varepsilon / \sin(\varepsilon+\phi)$$

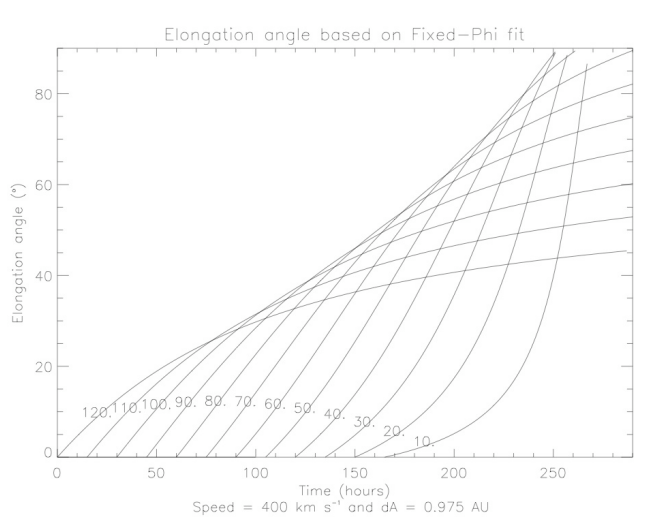
$$r_{PP} = d \sin\varepsilon$$

$$r = 2d \sin\varepsilon / (1+\sin(\varepsilon+\phi))$$

$$1/r = .5\,(1/r_{PP} + 1/r_{F\phi})$$

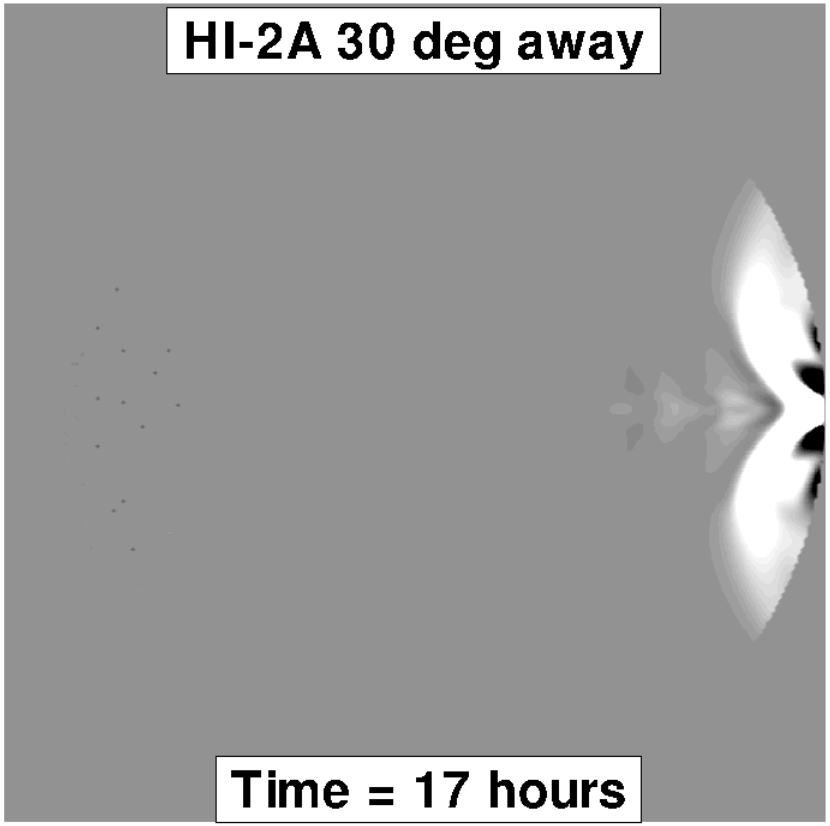
Simulations as controlled laboratory environment

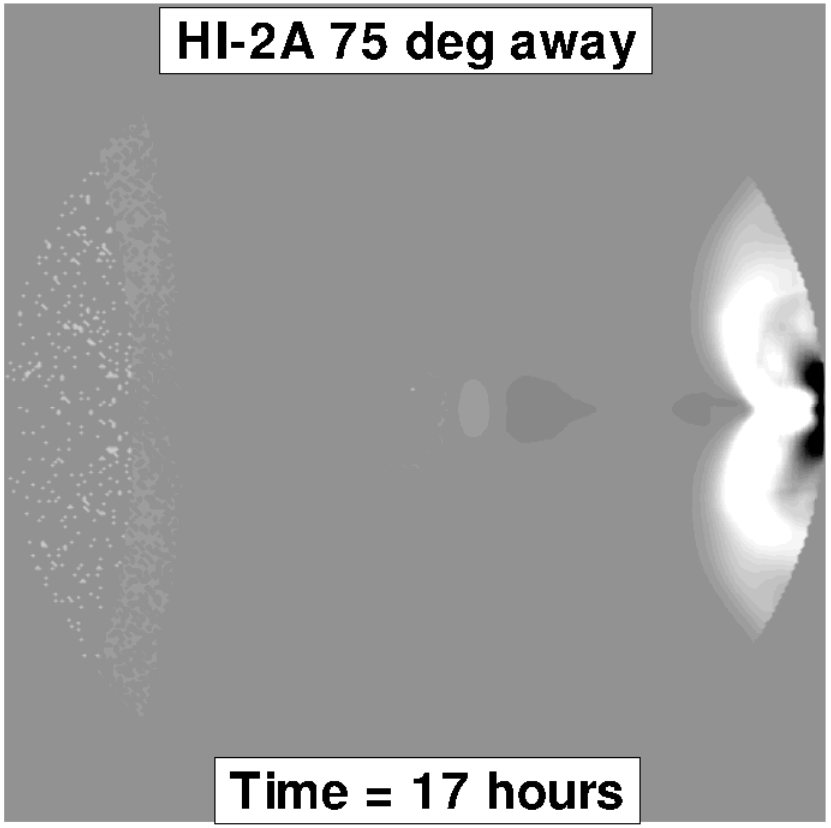
- Testing fitting methods to derive CME direction.
- Devised for plasma blobs/CIRs with 3 assumptions:
  - constant direction, — stereoscopic methods: Liu (2010), Lugaz (2010) in ApJ
  - small CME width, — statistical study or different assumption
  - constant speed. — statistical study difficult (lack of fast CMEs) Simulations



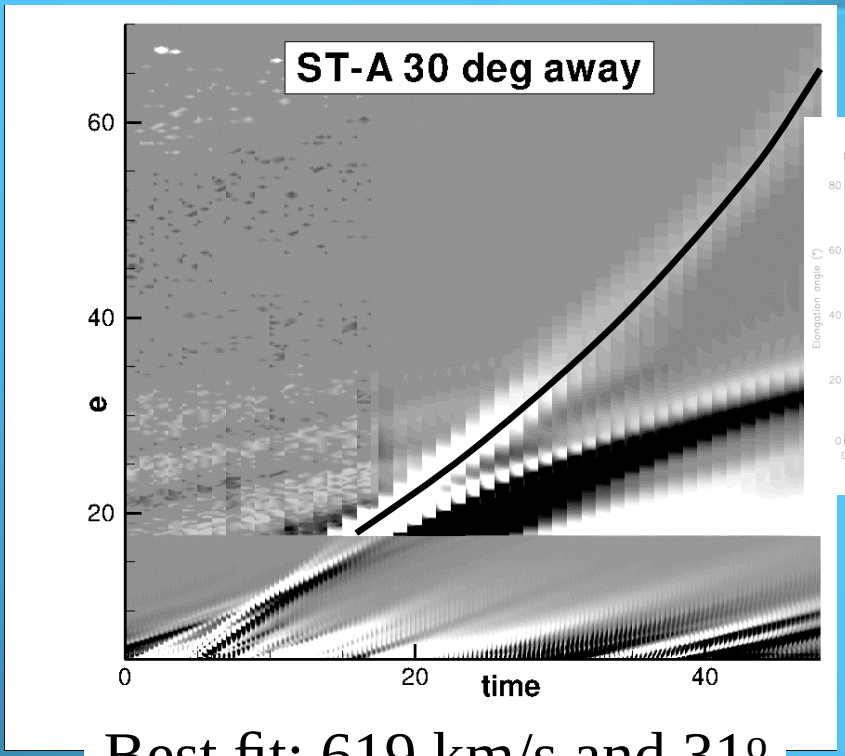
- Worst case scenario for fitting method:
  - Fast CME
  - Very wide
  - *In front of a coronal hole* (not done here)
- We do a simulation of a 800 km/s wide CME (at 20 Rs) into a solar minimum configuration (bipolar magnetic field).

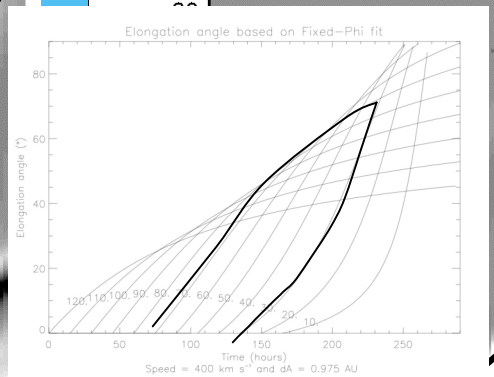
Same CME from 2 different view points

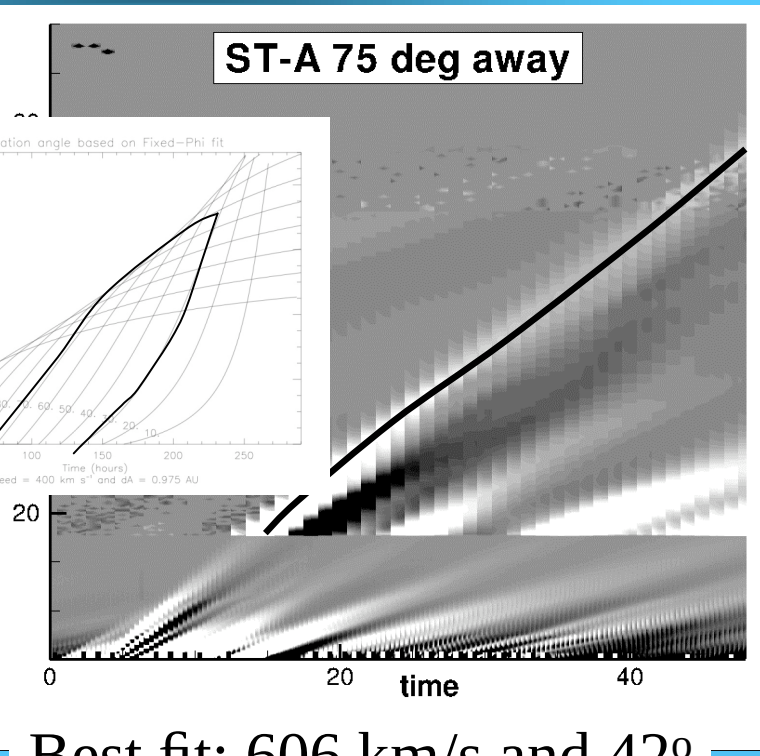




J-maps and direction







Best fit: 619 km/s and 31º
[585-659] and [22º,45º]

Best fit: 606 km/s and 42º
[561-694] and [27º,66º]

- "Geometrical" acceleration/deceleration not as clear as expected.
- Good for small directions (*halo CMEs*), large underestimation of large directions (*limb CMEs*).
- MORE at my poster tomorrow (EGU2010-3691).

Conclusion

- Simulations are an important tool in support of HI observations
- For complex events (CME-CME interaction):
  - What happened? (Lugaz et al., *Sol. Phys.,* 2009, Webb et al, *Sol Phys,* 09)
  - Testing different physical mechanisms (Lugaz et al., *Ann. Geo.,* 2009)
- To test and validate methods:
  - Simulations are like a controlled laboratory environment:
    - CME speed and direction are known,
    - Can vary only one parameter.
  - We tested the Fixed-Phi and Point-P approximations.
  - We devised a new approximation which fits better our simulated CME and is important at large elongation angles (beyond 40º).
  - Lack of fast/wide CMEs may explain why fitting method work so well so far.
- Thanks to NASA and NSF for funding.